PCT
Exp Mail EV335608130US
USAN 09/888,727
PERTY ORGANIZATION
Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 4 : F17D 1/16

A1

(11) International Publication Number: WO 89/ 01590

(43) International Publication Date: 23 February 1989 (23.02.89)

(21) International Application Number: PCT/AU87/00257

(22) International Filing Date: 10 August 1987 (10.08.87)

(71) Applicants *(for all designated States except US)*: AUSTRALIAN COMMERCIAL RESEARCH & DEVELOPMENT LIMITED [AU/AU]; A.M.P. Place, 10 Eagle Street, Brisbane, QLD 4000 (AU). CURTIN UNIVERSITY OF TECHNOLOGY [AU/AU]; Kent Street, Bentley, W.A. 6102 (AU).

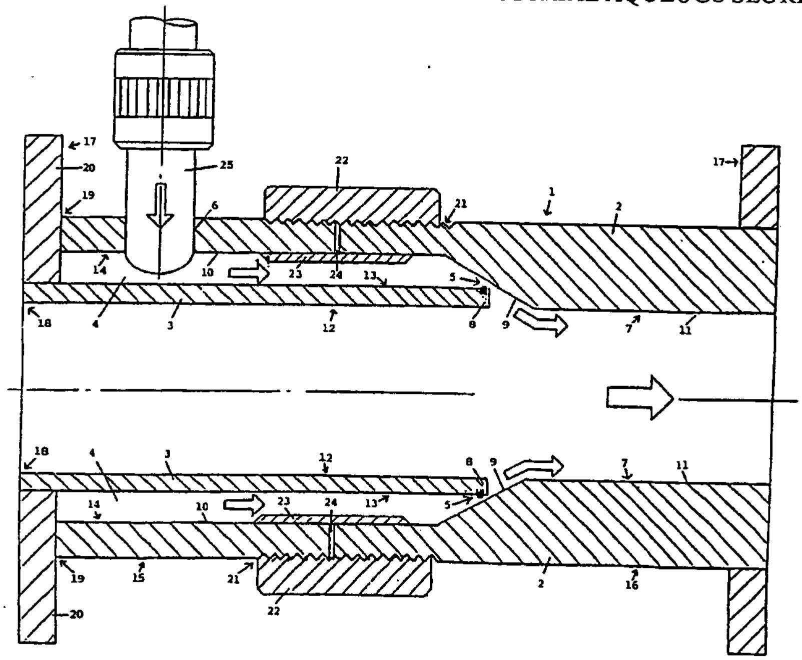
(72) Inventor; and
(75) Inventor/Applicant *(for US only)* : HORSLEY, Richard, Rowley [AU/AU]; 4 Caperton Court, Ferndale, W.A. 6155 (AU).

(74) Agent: E.F. WELLINGTON & CO.; 457 St. Kilda Road, Melbourne, VIC 3004 (AU).

(81) Designated States: AT, AT (European patent), AU, BB, BE (European patent), BG, BJ (OAPI patent), BR, CF (OAPI patent), CG (OAPI patent), CH, CH (European patent), CM (OAPI patent), DE, DE (European patent), DK, FI, FR (European patent), GA (OAPI patent), GB, GB (European patent), HU, IT (European patent), JP, KP, KR, LK, LU, LU (European patent), MC, MG, ML (OAPI patent), MR (OAPI patent), MW, NL, NL (European patent), NO, RO, SD, SE, SE (European patent), SN (OAPI patent), SU, TD (OAPI patent), TG (OAPI patent), US.

Published
With international search report.

(54) Title: PIPELINE TRANSPORTATION OF NATURAL OR INDUSTRIAL AQUEOUS SLURRIES



(57) Abstract

A method and apparatus is provided for reducing yield stress in pipeline transportation of slurries containing about 20% to 60% by weight of water and solids of a particle size range from about 0 to 150 μm, at high concentration and in which the bulk of the flow is considered a core flow. A viscosity-reducing agent is injected, or an admixture of the slurry with a viscosity-reducing agent is extruded, at the wall of the pipeline in which the slurry is being pumped, so that there is a viscosity modification of a relatively thin wall-layer of the slurry at the pipeline wall, whereby the bulk of the slurry is relatively unaltered for parallel flow with the thin wall-layer of the slurry along the pipeline under conditions of steady laminar flow.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	FR	France	ML	Mali
AU	Australia	GA	Gabon	MR	Mauritania
BB	Barbados	GB	United Kingdom	MW	Malawi
BE	Belgium	HU	Hungary	NL	Netherlands
BG	Bulgaria	IT	Italy	NO	Norway
BJ	Benin	JP	Japan	RO	Romania
BR	Brazil	KP	Democratic People's Republic of Korea	SD	Sudan
CF	Central African Republic			SE	Sweden
CG	Congo	KR	Republic of Korea	SN	Senegal
CH	Switzerland	LI	Liechtenstein	SU	Soviet Union
CM	Cameroon	LK	Sri Lanka	TD	Chad
DE	Germany, Federal Republic of	LU	Luxembourg	TG	Togo
DK	Denmark	MC	Monaco	US	United States of America
FI	Finland	MG	Madagascar		

PIPELINE TRANSPORTATION OF NATURAL OR INDUSTRIAL AQUEOUS SLURRIES

BACKGROUND OF THE INVENTION

This invention relates to a method and apparatus for reducing yield stress in the pipeline transportation of natural or industrial aqueous slurries, in pumping said slurries along extended distances of pipeline to a disposal area at high concentration and wherein the bulk of the flow is considered to be a core flow, said slurries containing water in the range of from about 60% to about 20% by weight and solids of a particle size distribution within the range of from about 0 to about 150μm, and generally having a viscosity greater than 0.1 Pascal second and up to about 100 Pascal second.

Although the method and apparatus of the invention is principally concerned with the pipeline transportation of bauxite suspension residue (red mud) resulting from operation of the Bayer alumina process, by pumping along the pipeline to disposal areas as hereinafter exemplified and described in detail, said method and apparatus are also adaptable for the pipeline transportation of slurries containing solids selected from other mineral tailings, nickel concentrates, gold ores, phosphate ores, lime, kaolin, brown coal, black coal, mineral sands, pulp paper, and sewerage or like effluent solids.

In general, the methoa and apparatus of the invention are adaptable for the pipeline transportation of slurries containing solids selected from <2μm clay-type particles; 2μm to 75μm silt-type particles; and >75μm sand-type particles. In particular, the method

and apparatus of the invention are adapted for the pipeline transportation of slurries such as bauxite residue (red mud) containing mineral tailings solids and water in the range of from about 50% by weight to about 30% by weight.

The Bayer alumina process produces large quantities of bauxite suspension residue (red mud) which is pumped to disposal. A typical alumina refinery in Australia, operating the Bayer process, produces some 10,000 tonnes per day of bauxite suspension residue. For instance, in Western Australia alone, the Bayer alumina refineries of Alcoa of Australia Limited, located at Kwinana and Pinjarra, Western Australia, generate in total some 7.5 million tonnes of bauxite residue annually, which is required to be pumped to disposal areas.

There are economic and environmental incentives for the disposal of Alcoa red mud suspension residue at the greatest possible solids concentration. The pipeline transportation over some kilometres of Alcoa red mud at a concentration of about 50% wt. solids is part of the desired disposal procedure, since it is desirable to pump the red mud suspension at the highest possible solids concentration. Red mud from other sites have differing solids concentration, for instance, Worsley red mud probably has a solids concentration of the order of 70% wt. solids.

In the disposal of red mud suspension residue from the Bayer process at concentrations of 50% wt. or larger, the yield stress of the suspension makes conventional pipeline disposal unsuitable owing to the very high pressure gradients generated. A reduction in the apparent viscosity of the mud, achieved by reducing the yield stress, would: increase the maximum through-

put for a given pipeline; reduce the number of pumping stations needed; and reduce the energy requirements.

Commercial viscosity-reducing agents or modifiers are available which, at low concentrations, reduce the yield stress very substantially. However, the large quantity of residue to be treated, and the zero value of the residue, make the use of even the cheapest available viscosity-reducing agents or modifiers uneconomic, if applied to the entire residue. There is therefore a need for the provision of a method and/or apparatus which materially reduces the pressure gradient of the slurry in pumping in the pipeline.

SUMMARY OF THE INVENTION

In accordance with one aspect of the present invention, there is provided a method for reducing yield stress in the pipeline transportion of natural or industrial aqueous slurries, in pumping such a slurry along extended distances of pipeline to disposal area at high concentration and wherein the bulk of the flow is considered to be a core flow, said slurries containing water in the range of from about 60% to about 20% by weight and solids having a particle size distribution within the range of from about 0 to about 150μm, which method comprises injecting a viscosity-reducing agent or modifier into the pipeline at the wall of the pipeline in which said slurry is being pumped so that there is viscosity-modification of only a relatively thin wall-layer of the slurry by said viscosity-reducing agent or modifier at the wall of the pipeline, leaving the bulk of the slurry relatively unaltered, for parallel flow of said thin wall-layer with the bulk of said slurry along the pipeline under conditions of steady laminar flow.

We have found, for instance, that the injection of a viscosity-reducing agent at the wall of a slurry pipe transporting red mud, results in the viscosity-modification of only a thin wall-layer of the mud at the wall of the slurry pipe, leaving the bulk of the mud relatively unaltered, and reduces the pressure gradient by a value as low as 30-35% of that observed with untreated mud at the same flow conditions. Moreover, only a fraction of the amount of the viscosity reducing agent that would be required for treatment of the total mud flow is needed for use in the procedure of the invention.

Experiments and tests which we have carried out, relating to the method of the invention as described above, involved injecting a commercially available viscosity-reducing agent (Freeviz 137, supplied by ICI Australia Operations Pty. Ltd., Adhesives Division of 19-25 Anne Street, St. Marys, New South Wales, Australia), at the wall of a 50 mm diameter pipe carrying red mud (Bayer process residue) in steady laminar flow, at an apparent wall shear rate 8V/D of 13-14 s^{-1}. Solids concentration was in the range 44.7-53.1% wt. A reduction in pressure gradient was observed of up to 70% below that for untreated mud. By injecting the viscosity-reducing agent at the wall of the pipe, the cost of the friction reduction by 70% was reduced to one third of the cost of treating the whole mud.

In accordance with another aspect of the present invention, there is provided an improvement in or modification of said method for reducing yield stress in the pipeline transportation of natural or industrial aqueous slurries, in pumping such slurry along extended distances of pipeline to a disposal area of high concentration and wherein the bulk of the flow

is considered to be a core flow, said slurries containing water in the range of from about 60% to about 20% by weight and solids having a particle distribution size within the range of from about 0 to about 150μm, which improvement or modification comprises extruding an admixture of the slurry or of the solids of the slurry with a viscosity-reducing agent or modifier into the pipeline at the wall of the pipeline in which said slurry is being pumped so that there is a relatively thin annular layer of said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent or modifier at the wall of the pipeline, around the slurry being pumped and which slurry is otherwise relatively unaltered, for parallel flow of said slurry being pumped along the pipeline under conditions of steady laminar flow. Said admixture generally has a viscosity of less than about one-third of the viscosity of the slurry being pumped.

We have found that extruding a layer of an admixture of the slurry or of the solids of the slurry with a viscosity-reducing agent at the wall of a slurry pipe transporting, for instance, red mud, results in an enhanced viscosity-modification of the transported red mud slurry at the wall of the slurry pipe, leaving the bulk of the mud relatively unaltered, and reduces the pressure gradient to a value as low as 70% of that observed with untreated mud at the same flow conditions, compared to the 30-35% reduction referred to above. Moreover, there is enhanced reduction in the amount of the viscosity-reducing agent that would be required for treatment of the total mud flow, compared with what is needed for use in the first-mentioned procedure of the invention.

Experiments and tests relating to the improvement in or modification of the method of the invention as described above, which we have carried out, involved extruding an admixture of red mud (Bayer process residue) and a commercially available viscosity-reducing agent (Freeviz 137) at the wall of a 50 mm diameter pipe carrying red mud (Bayer process residue) in steady laminar flow, at an apparent wall shear rate 8V/D of 13-14 s^{-1}. Solids concentration was in the range 44.7-53.1% wt. To achieve a drag reduction of 70% required, in said admixture for the extrusion method, 0.06% wt. of viscosity-reducing agent, related to the slurry being pumped, compared to 0.12% wt. of viscosity-reducing agent for the injection method. Hence there is a reduction of one half of the amount of viscosity-reducing agent required to achieve the same pressure drop. By extruding such admixtures of red mud and viscosity-reducing agent at the wall of the pipe, the cost of the friction reduction by 70% can be still further reduced more than to one third of the cost of treating the whole mud.

Results of pipeline tests are described below, in which each of: (I) a viscosity-reducing agent solution; and (II) an admixture of red mud and a viscosity-reducing agent solution, was injected/extruded at the wall of the pipe. Whereas for tests without injection of the viscosity-reducing agent solution, measured pressure gradient are in reasonable agreement with predictions using measured rheological properties, in the case of tests with: (I) a viscosity-reducing agent solution injection at the pipe wall, measured pressure gradients are as small as 31% of the values predicted from rheological properties; and (II) an admixture of red mud and a viscosity-reducing agent solution extrusion at the pipe wall, measured pressure gradients are

lowered by a value of 60% of said values, both measured on samples of the mud collected from these tests.

In accordance with yet another aspect of the present invention, there is provided apparatus suitable for operating the improvement in or modification of the method of the invention as described above, said apparatus comprising an injector unit adapted to be interposed in the pipeline and having: an outer tubular member; an inner tubular member; an annular chamber formed by the outer tubular member and the inner tubular member for accommodating a reservoir of said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent under positive pressure; an annular gap formed by the outer tubular member and the inner tubular member for extrusion of a relatively thin annular layer of said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent from said reservoir of the admixture against the bore of the pipeline; and an injection port or ports in the outer tubular member for injecting said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent into said annular chamber to provide said reservoir of the admixture under positive pressure.

EMBODIMENTS OF THE INVENTION

Although the methods of the invention are particularly useful for the pipeline transportation of bauxite suspension residue (red mud) as indicated above, said methods may equally well be used for the pipeline transportation of other such natural or industrial slurries. For example, the methods of the invention are useful for the pumping of ores such as gold ores, especially gold ores with soft water, or gold ores with higher clay contents which make them difficult to pump.

Any commercially available or otherwise known viscosity-reducing agents suitable for reducing the viscosity of suspensions or slurries of the kind indicated above, in particular, tannate-based or phosphate-based compositions having viscosity-reducing properties, may be utilised for operating the methods of the invention. For instance, known viscosity-reducing agents such as sodium orthophosphate ($Na_3PO_4.12 H_2O$) or sodium pyrophosphate ($Na_4P_2O_7$) or sodium hexametaphosphate ($Na(PO_3)_6$) or sodium tripolyphosphate ($Na_5P_3O_{10}$) or mixtures of them or compositions containing any one or more of them, may be so utilised. The commercially-available viscosity-reducing agent, Freeviz 137, referred to above, is believed to be a tannate-based composition.

Other commercially available viscosity-reducing agents suitable for pumping suspensions or slurries in accordance with the method of the invention are, for example, the FV 130-139 series, which are suitable for pumping red mud type of slurries; the FV 520-540 series, which are suitable for pumping gold ores with soft water; and the FV 570-590 series, which are suitable for gold ores with higher clay contents making them difficult to pump. However, in general all viscosity-reducing compositions such as the FV 474 series are useful for the purpose of the invention, in greater or lesser degrees. Each of these series of viscosity-reducing compositions is available from ICI Australia Operations Pty. Ltd. as referred to above.

A practical embodiment of the apparatus of the invention is illustrated in the accompanying drawings, which also illustrates apparatus for preparing said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent or modifier,

then pumping said admixture to the injector unit, as well as illustrate apparatus used for carrying out the experiments and tests referred to above, said drawings being as follows:

Fig. 1 is a longitudinal cross-section of the injector unit in accordance with the invention, adapted to be interposed in a pipeline as indicated above;

Fig. 2 is a longitudinal cross-section of another embodiment of the injector unit in accordance with the invention, adapted to be interposed in a pipeline as indicated above;

Fig. 3 diagrammatically illustrates apparatus for preparing said admixture, then pumping said admixture to the injector unit; and

Fig. 4 diagrammatically illustrates apparatus used for carrying out the experiments and tests referred to above.

Referring to the drawings, Fig. 1 shows an injector unit 1 adapted to be interposed in a pipeline 1A (see Fig. 3) and having an outer tubular member 2; an inner tubular member 3; an annular chamber 4 formed by the outer tubular member 2 and the inner tubular member 3 for accommodating a reservoir of said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent under positive pressure; an annular gap 5 formed by the outer tubular member 2 and the inner tubular member 3 for extrusion of a relatively thin annular layer of said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent from said reservoir of the admixture

against the bore of the pipeline; and an injection port 6 in the outer tubular member 2 for injecting said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent into said annular chamber 4 to provide said reservoir of the admixture under positive pressure.

Preferably, the outer tubular member 2 of the injector unit 1 has a bore 7 which is stepped inwardly downstream relative to the pipeline, with an inner end 8 of the inner tubular member 3 terminating adjacent the inward stepping of the bore 6 of the outer tubular member 2 so as to form said annular gap 5. More preferably, the inner end 8 of the inner tubular member 3 terminates adjacent an inclined face section 9 joining an upstream section 10 of the bore 7 of the outer tubular member 2 and a downstream section 11 of the bore 7 of the outer tubular member 2 approximately midway the length of the outer tubular member 2.

In particular, the outer tubular member 2 and the inner tubular member 3 of the injector unit 1 may be characterised and disposed in relation to each other such that: the bore 12 of said inner tubular member 3 is the same diameter as and is concentric with the bore 7 of the downstream section 11 of the outer tubular member 2 as well as with the bore of said pipeline; the outer surface 13 of said inner tubular member 3 is spaced from an upstream section 14 of the bore of said outer tubular member 2 to form the annular chamber 4 therebetween for accommodating a reservoir of said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent under positive pressure; the inner end 8 of said inner tubular member 3 is spaced from the inclined face section 9 joining said upstream section 14 of the bore of said outer tubular

member 2 to the downstream section 11 of the bore 7 of said outer tubular member 2 so as to form the annular gap 5 for extrusion of a relatively thin annular layer of said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent from said reservoir against said downstream section 11 of the bore of said outer tubular member 2 and around the flowing slurry in the pipeline; and the downstream section 11 of the bore 7 of said outer tubular member 2 is the same diameter as and is concentric with the bore of said pipeline; the injection port 6 in the outer tubular member 2 communicating with the annular chamber 4 formed by the upstream section 14 of the bore of the outer tubular member 2 and the outer surface 13 of the inner tubular member 3 for injecting said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent into said annular chamber 4 to provide the reservoir of said admixture under positive pressure for extrusion through said annular gap as indicated.

A feature of the injector unit, also illustrated in Fig. 1, is the provision of means therein for variation of the extrusion gap width whereby the relatively thin annular layer of said admixture of suspension or slurry and viscosity-reducing agent extruded against said downstream section 11 of the bore of said outer tubular member 2 and around the flowing suspension or slurry in the pipeline, can be varied in thickness. For instance, the outer tubular member 2 can be in two separate parts consisting of an upstream section 15 and a downstream section 16, with means for moving said upstream section 15 and said downstream section 16 either to advance towards or retract from each other in decreasing or increasing, respectively, the distance of the inner end 8 of said inner tubular member 3 from the bore 7 of the downstream

section of the outer tubular member 2, in particular, from the inclined face section 9 joining the upstream section 10 of the bore 7 of the outer tubular member 2 to the downstream section 11 of the bore 7 of the outer tubular member 2, in narrowing or widening said annular gap 5, there being a relationship between the dimension of said annular chamber 4 and said annular gap 5 such that the narrowest depth of the annular chamber 4 is always greater than the width of the annular gap 5.

The construction of the injector unit 1 of the invention preferably is such that it has an end connector flange 17 at each end of the unit for connecting the injector unit 1 to the pipeline in interposing said injector unit 1 in the pipeline, with an outer end 18 of the upstream section of the inner tubular member 3 being fixed to the outer end 19 of the upstream section 15 of the outer tubular member 2, conveniently by way of the upstream end connector flange member 20, the outside surfaces of the adjoining end portions of the upstream end section 15 and the downstream end section 16 of the outer tubular member 2 being screw-threaded at 21 and associated with a co-acting screw-threaded nut 22 for rotation to advance or retract the upstream end section 15 and the downstream end section 16 of the outer tubular member 2 towards or away from each other. An internal sealing sleeve 23 is fitted to the inside surfaces of the adjoining end portions of the upstream end section 15 and the downstream end section 16 of the outer tubular member 2 in order to seal the outer tubular member 2 from loss of said admixture of suspension or slurry and viscosity-reducing agent under pressure through space 24 between the adjoining ends of said sections.

A single injection port 6 with injection nozzle 25 fitted thereto may be located in the upstream section 15 of the outer tubular member 2 for supplying the admixture of suspension or slurry and viscosity-reducing agent to said annular chamber, or, as illustrated in Fig. 2 of the accompanying drawings, a plurality of radially-disposed injection ports 26 each with an injection nozzle fitted thereto may be located in a manifold 27 forming part of said upstream section 15 of the outer tubular member 2, so as to lessen or eliminate any tendency of the admixture to swirl in the course of extrusion through said annular gap 5 to form said annular thin wall-layer of the admixture at the wall of the pipeline, around the slurry in the pipeline.

Preparation and feeding of said admixture of slurry and viscosity-reducing agent to the injector unit may be effected by utilising the equipment illustrated in Fig. 3 of the accompanying drawings. Thus, a selected quantity of the slurry and a selected quantity of the viscosity-reducing agent preferably in solution form, may be added to a mixing vessel 28 and thoroughly mixed therein say by a helical ribbon mixer device 29 to form a so-called treated mud for introduction at the wall of the pipeline via the injector unit 1 as described above. For instance, the admixture may be conveyed by pipe 30 from the mixing vessel to appropriate pump means such as a mono-pump 31, which pumps the admixture to the annular chamber 4 of the injector unit 1 by piping 32 under positive pressure as described above.

In the full-scale pumping transportation of Bayer alumina process red mud to a disposal area as described above, a pipeline of 300 mm diameter is

ordinarily utilised for the purpose, and as excessive pumping pressure is required as a function of the pipe length and solids concentration, and as the red mud is highly corrosive due to alkalinity of the order of pH 14, besides containing chloride ions, the material of construction for the pipeline needs to be chosen accordingly. Generally, a high nickel-content alloy resistant to chloride ions is used for fabricating the pipeline, however, a high-strength pipeline fabricated from high-strength plastics compositions such as carbonfibre plastics, or other suitable material, may be used for the purpose. A high nickel-content alloy or a high-strength plastics composition, or other suitable material, may also be used for fabricating the injector unit of the invention.

The experiments and tests referred to above were carried out on red mud resulting from operation of the Bayer alumina process, using the equipment shown in Fig. 4 of the accompanying drawings, in which the following numerals designate the indicated items of equipment: 100 and 101 = 200 litre red mud supply and mixing drums in which the experimental slurry is prepared; 102 = mono pump for pumping the slurry; 103 = 50 mm PVC pipeline; 104 = injector unit; 105 = pressure gauges; 106 = 200 litre discharge drum; and 107/108/109 = 20 litre red mud and viscosity-reducing agent mixing drum, mono pump and piping, respectively, for use in operating the extrusion method.

According to Boger et al [Boger, D.V., Sarmiento, G., Uhlherr, P.H.T., 7th Aust. Conf. on Chem. Eng. (1979)], red mud is a yield-pseudoplastic fluid at concentrations above 33% wt. An appropriate rheological model for this type of fluid is the Herchel-Bulkley equation : ASTM Vol. 26 p. 621 (1926):

$$\tau = \tau_y + K\dot{\gamma}^n \qquad (1)$$

where K is the consistency parameter; n is the flow-behaviour index; and τ_y is the yield stress. K and n are readily determined from concentric-cylinder viscometry and the yield stress from yield vane.

An alternative rheological model is the power law:

$$\tau = K\dot{\gamma}^n \qquad (2)$$

where K and n are as for the Herchel-Bulkley equation. This model fails at zero shear rate; it cannot account for the presence of a yield stress. However, this is not a serious shortcoming in pipe-flow analysis since the existence of a yield stress does not influence this procedure nor the result, i.e. the behaviour in the low-shear region near the centre of the pipe is unimportant in determining wall behaviour and hence friction.

The rheological behaviour of red mud is also conveniently approximated by the Bingham fluid model, in which the non-linearity at low shear rates is ignored:

$$\tau = \tau_{yB} + \eta \dot{\gamma} \qquad (3)$$

Thus, two rheological parameters are required; the Bingham yield stress τ_{yB}, and the plastic viscosity η. Again these parameters are readily determined from concentric-cylinder viscometry.

The rheological parameters of the red mud slurry were determined using a HAAKE Rotovisco RV12 viscometer. The sensor system used consisted of a standard MVIIP profiled rotor but with a modified outer sleeve and rotating cup arrangement developed specifically to enable the

viscosity of settling suspension to be measured, Overend et al : Proc IX Int. Congress on Rheology, p 583 (1984).

The shear rate was uniformly increased and decreased using a programming unit (HAAKE PG142) and shear rate - shear stress rheograms were plotted using an x-y recorder. All tests were carried out at 25^{o}C on well-mixed samples of mud which had been strained to remove large fibrous debris. Shearing was continued until equilibrium properties were obtained. The yield stress of red mud slurry was determined using a star shaped yield vane rotated at 0.1 min^{-1}, Nguyen and Boger : Nat. Conf. on Rheology. (2nd), p19. (1981).

Shear rate corrections were applied to the viscometric data obtained. For the case of yield/power law fluids the shear rate was corrected as for Krieger and Maron, Journal of Applied Physics, Vol. 25, p72 (1954), and for Bingham parameters the Reiner-Rivlin correction was applied, Bird et al : Transport Phenomena, John Wiley, New York, (1960). For the geometry used the Reiner-Rivlin correction was a constant 8.6%. All rheological parameters are summarised in Table 1 below:

TABLE 1 RHEOLOGICAL PARAMETERS OF MUD SAMPLES

TEST NO.	UNTREATED MUD (M)				TREATED MUD (TM)				TOTAL MUD (M+TM)			
	BINGHAM PARAMETERS		POWER-LAW PARAMETERS		BINGHAM PARAMETERS		POWER-LAW PARAMETERS		BINGHAM PARAMETERS		POWER-LAW PARAMETERS	
	τ_y(Pa)	η(Pas)	K(Pas^n)	n(-)	τ_y(Pa)	η(Pas)	K(Pas^n)	n(-)	τ_y(Pa)	η(Pas)	K(Pas^n)	n(-)
1	58.8	0.072	50.0	0.053	48.4	0.058	36.1	0.086	59.8	0.072	51.2	0.052
2	71.1	0.037	65.4	0.030	21.8	0.052	20.3	0.052	50.7	0.068	48.8	0.036
3	74.5	0.062	56.9	0.077	18.6	0.049	12.8	0.114	67.3	0.062	53.0	0.076
4	53.6	0.056	45.9	0.050	8.4	0.049	3.9	0.254	51.2	0.042	44.1	0.045
5	155.9	0.041	139.3	0.046	7.9	0.004	1.9	0.426	127.7	0.057	108.4	0.059

The pressure gradient for the steady-laminar flow of red mud can be predicted either from the Bingham model parameters or from the yield/power law parameters.

Bingham Behaviour:

The Buckingham equation, Buckingham : ASTM, Vol. 21, p1154 (1921), gives the pressure gradient for a Bingham plastic in pipe flow:

$$\frac{24Vn}{D\ \tau_{yB}} = 3\ \frac{\tau_w}{\tau_{yB}} - 4\left(\frac{\tau_{yB}}{\tau w}\right)^3 \qquad (4)$$

$$\text{where } \tau_w = \frac{D\Delta P}{4L} \qquad (5)$$

Power Law Behaviour:

If power law behaviour is assumed, the pressure gradient can be determined directly from a rheogram of shear stress/shear rate as described by Govier and Aziz : Litton Educational Publishing, Inc., (1971). The wall shear stress resulting from steady state laminar flow can be determined from:

$$\frac{2V}{D} = \frac{n}{1+3n}\left(\tau_w\right)^{1/n}\left(\frac{1}{K}\right)^{1/n} \qquad (6)$$

From this the pressure gradient is calculated by (5).

Yield-Power Law Behaviour:

The wall shear stress produced by a yield pseudoplastic fluid can be determined from:

$$\frac{2V}{D} = \frac{\frac{1}{K}^{1/n}}{\tau_w{}^3}\left(\tau_w - \tau_y\right)^{\frac{(1+n)}{n}}\left[\frac{(\tau_w - \tau_y)^2}{\frac{1+3n}{n}} + 2\,\frac{\tau_y(\tau_w - \tau_y)}{\frac{1+2n}{n}} + \frac{\tau_y{}^2}{\frac{1+n}{n}}\right] \qquad (7)$$

Again, the pressure gradient is calculated from (5), the meaning of the symbols used in the foregoing equations being as follows:

D = pipe diameter, m.
K = power-law consistency parameter, Pa s^n.
L = pipe length, m.
n = power-law flow behaviour index, -.
ΔP = pressure difference, kPa.
V = velocity, ms^{-1}.
γ = shear rate, s^{-1}.
η = plastic viscosity, Pa s.
τ = shear stress, Pa.
τ_w = wall shear stress, Pa.
τ_y = yield stress, Pa.
τ_{yB} = Bingham yield stress, Pa.

Bauxite residue obtained from Alcoa, Kwinana, W.A., of solids concentration in the range 46.8 to 53.3 wt% was pumped through a smooth, horizontal pipe of 50 mm diameter using a variable speed mono pump. The volume flow rate of the red mud was maintained constant to give a value of apparent shear rate (8V/D) of 13 - 14 s^{-1} for all pipe test runs. This was done to simulate the conditions that a full-scale pipeline of 300 mm diameter would incur at a flow velocity of 0.5 m/s.

The red mud was supplied from a 200 litre drum which was slowly stirred with a helical ribbon mixer. The flow-rate of the mud flow was determined by timed collection from the discharge of the test section.

Prior to testing, a 20 litre drum of the red mud was treated with the viscosity-reducing agent, Freeviz 137. The treated mud was kept in suspension by a small helical ribbon mixer and extruded, using a small mono pump, through an annular slot leading to the pipe bore as described above. The rate of treated mud injection was measured by loss in weight of the 20 litre feed reservoir. The pressure gradient was measured at two points, 10 m and 5 m from the exit point, the first

pressure tapping being 2 m downstream of the point of treated mud extrusion. The test section discharged at atmospheric pressure and pipe pressures were measured by diaphragm protected Budenberg gauges. A 1 m clear section of acrylic pipe was installed immediately after extrusion to allow observation of the flow behaviour.

The pipe system was allowed to run with no treated mud injection until steady flow conditions were achieved. Flowrate and pressure gradient were recorded and a sample of mud was taken for rheological analysis. Injection of treated mud was commenced and again, once stable conditions were attained, flow rate and pressure gradient recorded and a sample of mud flow taken. A sample of treated mud was also retained for analysis and these samples were used to indicate the existence or otherwise of friction reduction. Solids concentration was determined by drying a known mass of mud at 110^{o}C and making a correction for the dissolved solids in the liquor. Mud density, where required, was obtained by calculation from the solids concentration.

A summary of the operating conditions and experimental results is given in Table II below. This table shows the ratio of treated mud to total mud flow and the observed friction or drag reduction. The ratio of treated mud to total mud flow allows the effective dose level to be calculated from the percentage of viscosity-reducing agent used to treat the mud. The observed friction or drag reduction is calculated as a percentage reduction in pressure gradient for untreated mud and total mud flow through the pipe. This column of Table II clearly shows that the degree of friction reduction observed increases with increasing addition of viscosity-reducing agent to the mud, and this is graphically represented in Figure A below.

TABLE II SUMMARY OF EXPERIMENTAL RESULTS

TEST NO.	UNTREATED MUD			TREATED MUD			TOTAL MUD			RATIO OF TREATED TO TOTAL MUD FLOW	EFFECTIVE DOSE LEVEL	OBSERVED FRICTION REDUCTION
	SOLIDS CONCENT-RATION	MASS FLOW RATE	PRESSURE GRADIENT	SOLIDS CONCENT-RATION	MASS FLOW RATE	REAGENT ADDITION	SOLIDS CONCENT-RATION	MASS FLOW RATE	PRESSURE GRADIENT			
	(wt%)	(kg/s)	(kPa/m)	(wt%)	(kg/s)	(wt%)	(wt%)	(kg/s)	(kPa/m)	(%)	(wt%)	(%)
1	47.5	0.247	5.9	47.7	0.022	0.2	47.5	0.256	4.9	8.4	0.017	17
2	47.8	0.245	6.0	47.4	0.024	0.35	47.8	0.241	3.6	10.0	0.035	40
3	47.8	0.242	5.8	47.7	0.023	0.50	47.8	0.263	3.0	8.6	0.043	48
4	46.8	0.239	5.0	46.9	0.022	0.70	46.9	0.275	1.6	8.0	0.056	68
5	53.3	0.284	13.2	52.9	0.029	1.00	53.0	0.383	2.8	7.7	0.077	79

TABLE III COMPARISON OF MEASURED AND PREDICTED PRESSURE GRADIENTS

TEST NO.	UNTREATED MUD PRESSURE GRADIENT (kPa/m)			TREATED MUD PRESSURE GRADIENT (kPa/m)		TOTAL MUD PRESSURE GRADIENT (kPa/m)		
	MEASURED	PREDICTED		PREDICTED		MEASURED	PREDICTED	
		BINGHAM	POWER-LAW	BINGHAM	POWER-LAW		BINGHAM	POWER-LAW
1	5.9	5.2	4.6	4.3	3.6	4.9	5.3	4.7
2	6.0	6.2	5.7	2.0	1.8	3.6	4.4	4.3
3	5.8	6.4	5.6	1.7	1.4	3.0	5.9	5.2
4	5.0	4.7	4.2	0.8	0.6	1.6	4.5	4.0
5	13.2	13.0	12.7	0.7	0.5	2.8	10.9	10.3

TABLE IV COMPARISON OF OBSERVED AND EXPECTED DRAG REDUCTION

TEST NO.	EFFECTIVE DOSE LEVEL (wt%)	DRAG REDUCTION (%)		
		OBSERVED	EXPECTED REDUCTION	
			BINGHAM	POWER-LAW
1	0.017	17	18	22
2	0.035	40	68	68
3	0.044	48	73	75
4	0.056	68	82	85
5	0.076	79	95	96

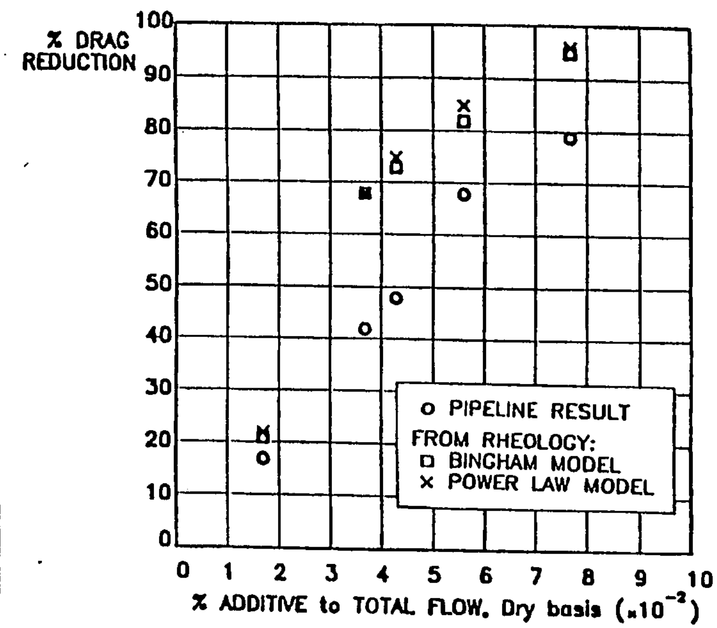


FIGURE A. OBSERVED AND EXPECTED DRAG REDUCTION

Table III shows the comparison between measured and predicted pressure gradients for each mud flow regime, (i.e. untreated; initial mud flow, treated; mud treated with Freeviz 137 and extruded into the periphery of the pipe, and total; the mud resulting from the extrusion of treated mud plus the untreated mud flow).

Figure A also shows the percentage drag reduction as determined from the untreated and treated mud predicted pressure gradients which represents the greatest percentage drag reduction possible.

The results of Table III indicate that, by extruding mud, pre-treated with Freeviz 137, at the pipe wall, the pressure gradient can be reduced to a degree requiring a greater quantity of reagent if the entire flow was treated.

It is, however, evident that the optimum possible result, as determined from the rheology and shown in Figure A, is not attainable. No definite explanation can be provided for this behaviour, although a number of reasons can be advanced.

Firstly, the wall layer of treated mud may experience conditions of high shear depending upon the layer thickness and hence viscous forces may be higher than expected. However due to the relatively low values of plastic viscosity (Bingham) and the flow behaviour index (Power-law) for all muds, the viscous forces which result are minimal when compared to the force required to overcome the yield stress.

Secondly, the differences may be due to variations in mud properties. Care was taken to maintain the solids concentration of untreated and treated muds the same. Nevertheless as Table II shows these solid

concentrations differ by 0.21% for run 3 to 0.84% for run 5, and hence some stratification of the treated layer may have occurred (i.e. the treated layer mud may migrate towards the top or bottom of the pipe). This effect should be negated by maintaining equal solid concentrations for untreated and treated mud.

Thirdly, most likely, the central core of untreated mud flow would tend to have the loading characteristics of a column under an axial force. With the peripheral layer of treated mud possessing a lower yield stress than the core mud, the column of core mud could buckle along the entire length of the pipe. The result of this occurrence is the development of alternative pockets of treated and untreated mud in contact with the wall of the pipe, and hence a decrease in the drag reduction as predicted from rheology tests.

TABLE V. COMPARISON BETWEEN VISCOSITY-REDUCING AGENT INJECTION AND TREATED MUD EXTRUSION

TEST NO.	REAGENT INJECTION		TEST NO.	TREATED MUD INJECTION	
	EFFECTIVE DOSE LEVEL (wt%)	DRAG REDUCTION (%)		EFFECTIVE DOSE LEVEL (wt%)	DRAG REDUCTION (%)
4	0.067	56	1	0.017	17
6	0.320	62	2	0.035	40
8	0.114	69	3	0.044	48
12	0.031	25	4	0.056	68
14	0.016	25	5	0.076	79

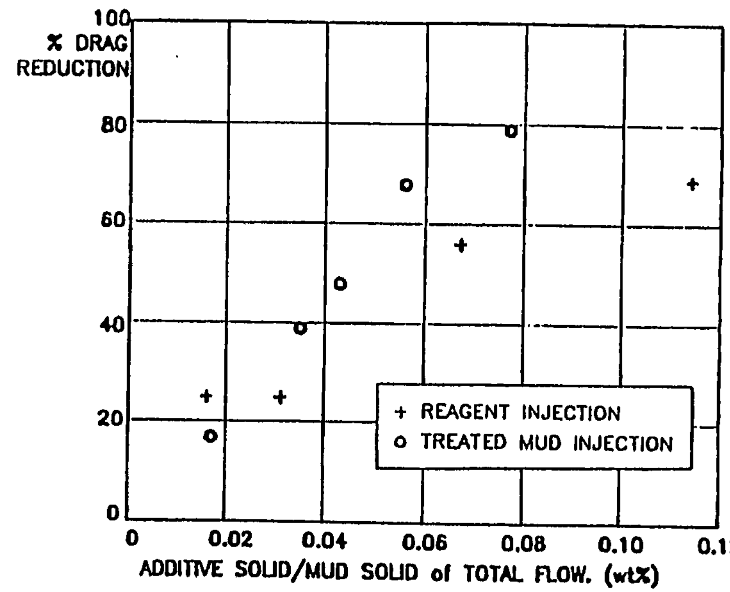


FIGURE B. VISCOSITY-REDUCING AGENT AND TREATED MUD EXTRUSION

A comparison between treated mud extrusion and viscosity-reducing agent injection, is given in Table V. Figure B represents the results from Table V and indicates how each method of drag reduction is related. The results for neat reagent injection, although limited in number, tend to show a greater degree of scatter than those for treated mud extrusion.

Using the results obtained to achieve a drag reduction of 70% would require 0.06% additive solid to mud solid of total flow for treated mud extrusion as compared to 0.12% for viscosity-reducing agent injection. Hence there is a reduction of one half of the amount of such agent required to achieve this same pressure drop.

By the extrusion of treated mud, a wall layer is produced which is relatively stable and also much thicker than that produced by a very small rate of injection of a solution of viscosity-reducing agent. The cost of drag reduction can be calculated from the experiments, taking the current cost of Freeviz 137 as A$2.30/kg.

A 70% reduction in pressure gradient at current costs would require: (i) for treatment of total mud flow, A$8.05 per tonne of dry solids pumped; (ii) for injection of viscosity-reducing agent, A$2.70 per tonne of dry solids pumped; and (iii) for the extrusion of treated mud, A$1.35 per tonne of dry solids pumped. Although the optimum result at current cost of A$0.50 per tonne of dry solids pumped has not been achieved, the additive cost required to obtain a pressure gradient reduction of 70% has been reduced by treating the mud at the wall of the pipe.

Altogether, it will be seen that: (a) reduction in the pressure gradient is achieved by the injection of

viscosity-reducing agent at the wall of a laminar pipe flow of bauxite residue mud; (b) a greater reduction in the pressure gradient is observed by the extrusion at the pipe wall of a thin layer of such mud pre-treated with viscosity-reducing agent; and (c) the cost of chemically treating bauxite residue can be reduced by a factor of six (6) if mud pre-treated with viscosity-reducing agent is extruded against the internal wall of a pipe flowing with bauxite residue mud.

CLAIMS:

1. A method for reducing yield stress in the pipeline transportation of natural or industrial aqueous slurries, in pumping said slurries along extended distances of pipeline to a disposal area at high concentration and wherein the bulk of the flow is considered to be a core flow, said slurries containing water in the range of from about 60% to about 20% by weight and solids of a particle size distribution within the range of from about 0 to about 150μm, which method comprises injecting a viscosity-reducing agent or modifier into the pipeline at the wall of the pipeline in which said slurry is being pumped so that there is viscosity-modification of only a relatively thin wall-layer of the slurry by said viscosity-reducing agent or modifier at the wall of the pipeline, leaving the bulk of the slurry relatively unaltered, for parallel flow of said thin wall-layer with the bulk of said slurry along the pipeline under conditions of steady laminar flow.

2. A method as claimed in claim 1 wherein the solids in the slurry are selected from mineral tailings, nickel concentrates, gold ores, phosphate ores, iron ores, lime, kaolin, brown coal, black coal, mineral sands, pulp paper, and sewerage or like effluent solids.

3. A method as claimed in claim 1 wherein the slurry contains solids selected from <2μm clay-type particles; 2μm to 75μm silt-type particles; and >75μm sand-type particles.

4. A method as claimed in claim 1 wherein the slurry contains mineral tailings solids and water in the range of from about 50% by weight to about 30% by weight.

5. A method as claimed in claim 4 wherein the slurry of mineral tailings solids is bauxite residue (red mud) resulting from operation of the Bayer alumina process.

6. A method as claimed in any one of claims 1 to 5 wherein the viscosity-reducing agent or modifier is selected from tannate-based compositions and phosphate-based compositions.

7. A method as claimed in any one of claims 1 to 6 wherein an aqueous solution of the viscosity-reducing agent or modifier is injected at the wall of the pipeline.

8. A method for reducing yield stress in the pipeline transportation of natural or industrial aqueous slurries, in pumping said slurries along extended distances of pipeline to a disposal area at high concentration and wherein the bulk of the flow is considered to be a core flow, said slurries containing water in the range of from about 60% to about 20% by weight and solids of a particle size distribution within the range of from about 0 to about 150μm, which method comprises extruding an admixture of the slurry or of the solids of the slurry with a viscosity-reducing agent or modifier into the pipeline at the wall of the pipeline in which said slurry is being pumped so that there is a relatively thin annular layer of said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent or modifier at the wall of the pipeline, around the slurry being pumped and which slurry is otherwise relatively unaltered, for parallel flow of said slurry being pumped along the pipeline under conditions of steady laminar flow.

9. A method as claimed in claim 8 wherein the solids in the slurry and in the admixture are selected from mineral tailings, nickel concentrates, gold ores, phosphate ores, iron ores, lime, kaolin, brown coal, black coal, mineral sands, pulp paper, and sewerage or like effluent solids.

10. A method as claimed in claim 8 wherein the slurry and the admixture contains solids from $<2\mu m$ in clay-type particles; $2\mu m$ to $75\mu m$ silt-type particles; and$>75\mu m$ sand-type particles.

11. A method as claimed in claim 8 wherein the slurry and the admixture contains mineral tailings solids and water in the range of from about 50% by weight to about 30% by weight.

12. A method as claimed in claim 11 wherein the slurry and the admixture of mineral tailings solids is bauxite residue (red mud) resulting from operation of the Bayer alumina process.

13. A method as claimed in any one of claims 8 to 12 wherein the viscosity-reducing agent or modifier is selected from tannate-based compositions and phosphate-based compositions.

14. A method as claimed in any one of claims 8 to 13 wherein an admixture of the slurry or the solids of the slurry and an aqueous solution of the viscosity-reducing agent or modifier is extruded at the wall of the pipeline.

15. Apparatus suitable for operating a method for reducing yield stress in the pipeline transportation of natural or industrial aqueous slurries, in pumping

said slurries along extended distances of pipeline to a disposal area at high concentration and wherein the bulk of the flow is considered to be a core flow, said slurries containing water in the range of from about 60% to about 20% by weight and solids of a particle size distribution within the range of from about 0 to about 150μm, by extruding an admixture of the slurry or of the solids of the slurry with a viscosity-reducing agent or modifier into the pipeline at the wall of the pipeline in which said suspension or slurry is being pumped so that there is a relatively thin annular layer of said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent or modifier at the wall of the pipeline, around the slurry being pumped and which slurry is otherwise relatively unaltered, for parallel flow of said slurry being pumped along the pipeline under conditions of steady laminar flow, said apparatus comprising an injector unit adapted to be interposed in the pipeline and having: an outer tubular member; an inner tubular member; an annular chamber formed by the outer tubular member and the inner tubular member for accommodating a reservoir of said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent under positive pressure; an annular gap formed by the outer tubular member and the inner tubular member for extrusion of a relatively thin annular layer of said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent from said reservoir of the admixture against the bore of the pipeline; and an injection port or ports in the outer tubular member for injecting said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent into said annular chamber to provide said reservoir of the admixture under positive pressure.

16. Apparatus as claimed in claim 15 wherein the outer tubular member of the injector unit has a bore which is stepped inwardly downstream relative to the pipeline, with an inner end of the inner tubular member terminating adjacent the inward stepping of the bore of the outer tubular member so as to form said annular gap.

17. Apparatus as claimed in claim 15 wherein an inner end of the inner tubular member terminates adjacent an inclined face section joining an upstream section of the bore of the outer tubular member and a downstream section of the bore of the outer tubular member approximately midway the length of the outer tubular member.

18. Apparatus as claimed in claim 15 wherein an upstream section of the outer tubular member has an injection port or ports with an injection nozzle or nozzles fitted thereto for supplying the admixture of the slurry or the solids of the slurry with the viscosity-reducing agent to said annular chamber.

19. Apparatus as claimed in claim 15 wherein an upstream section of the outer tubular member comprises a manifold having a plurality of radially-disposed injection ports each with an injection nozzle fitted thereto for supplying the admixture of the slurry or the solids of the slurry with the viscosity-reducing agent to said annular chamber.

20. Apparatus as claimed in claim 15 wherein the outer tubular member and the inner tubular member are characterised and disposed in relation to each other such that: the bore of said inner tubular member is the same diameter as and is concentric with the bore of the downstream section of the outer tubular member

as well as with the bore of said pipeline; the outer surface of said inner tubular member is spaced from an upstream section of the bore of said outer tubular member to form the annular chamber therebetween for accommodating a reservoir of said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent under positive pressure; the inner end of said inner tubular member is spaced from an inclined face section joining said upstream section of the bore of said outer tubular member to a downstream section of the bore of said outer tubular member so as to form an annular gap for extrusion of a relatively thin annular layer of said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent from said reservoir against said downstream section of the bore of said outer tubular member and around the flowing slurry in the pipeline; the downstream section of the bore of said outer tubular member is the same diameter as and is concentric with the bore of said pipeline; and an injection port or ports in the outer tubular member communicates with the annular chamber formed by the upstream section of the bore of the outer tubular member and the outer surface of the inner tubular member for injecting said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent into said annular chamber to provide the reservoir of said admixture under positive pressure for extrusion through said annular gap.

21. Apparatus as claimed in any one of claims 15 to 20 comprising means for varying the width of the extrusion gap so that the annular layer of said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent extruded against a downstream section of the bore of said outer tubular member and around the flowing slurry in the pipeline, can be varied in thickness.

22. Apparatus as claimed in claim 21 wherein said means is adapted to move the upstream section and the downstream section of the outer tubular member so as to decrease or increase the distance of the inner end of said inner tubular member from an inclined face section joining the upstream section of the bore of the outer tubular member to the downstream section of the bore of the outer tubular member.

23. Apparatus as claimed in claim 21 or 22 wherein the outer tubular member comprises an upstream section and a separate downstream section, with means for moving said upstream section and said downstream section either to advance towards or retract from each other in decreasing or increasing, respectively, the distance of the inner end of said inner tubular member from the bore of the downstream section of the outer tubular member, in narrowing or widening said annular gap, whereby there is a relationship between the dimension of said annular chamber and said annular gap such that the narrowest depth of the annular chamber is always greater than the width of the annular gap.

24. Apparatus as claimed in any one of claims 21 to 23 wherein the injector unit has end connector flanges for connecting the injector unit to the pipeline, an outer end of the upstream section of the inner tubular member fixed to the outer end of the upstream section of the outer tubular member by an upstream end connector flange member, the outside surfaces of adjoining end portions of the upstream end section and the downstream end section of the outer tubular member being screw-threaded and associated with a co-acting screw-threaded nut for rotation to advance or retract the upstream end section and the downstream end section of the outer tubular member towards or away from each other, with an internal sealing sleeve fitted to the inside surfaces

of the adjoining end portions of the upstream end section and the downstream end section of the outer tubular member to seal the outer tubular member from loss of said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent under pressure through space between the adjoining ends of said sections.

24. Apparatus as claimed in any one of claims 15 to 24 in combination with means for preparing and feeding said admixture of the slurry or the solids of the slurry with the viscosity-reducing agent to the injector unit.

25. Apparatus as claimed in claim 24 wherein said means comprises a mixing vessel fitted with a helical ribbon or other such mixer device and connected by piping to a mono-pump or other such positive pressure pump for pumping said admixture of the slurry or the solids of the slurry with viscosity-reducing agent to said annular chamber of the injector unit under positive pressure via piping which connects said pump to the injector unit.

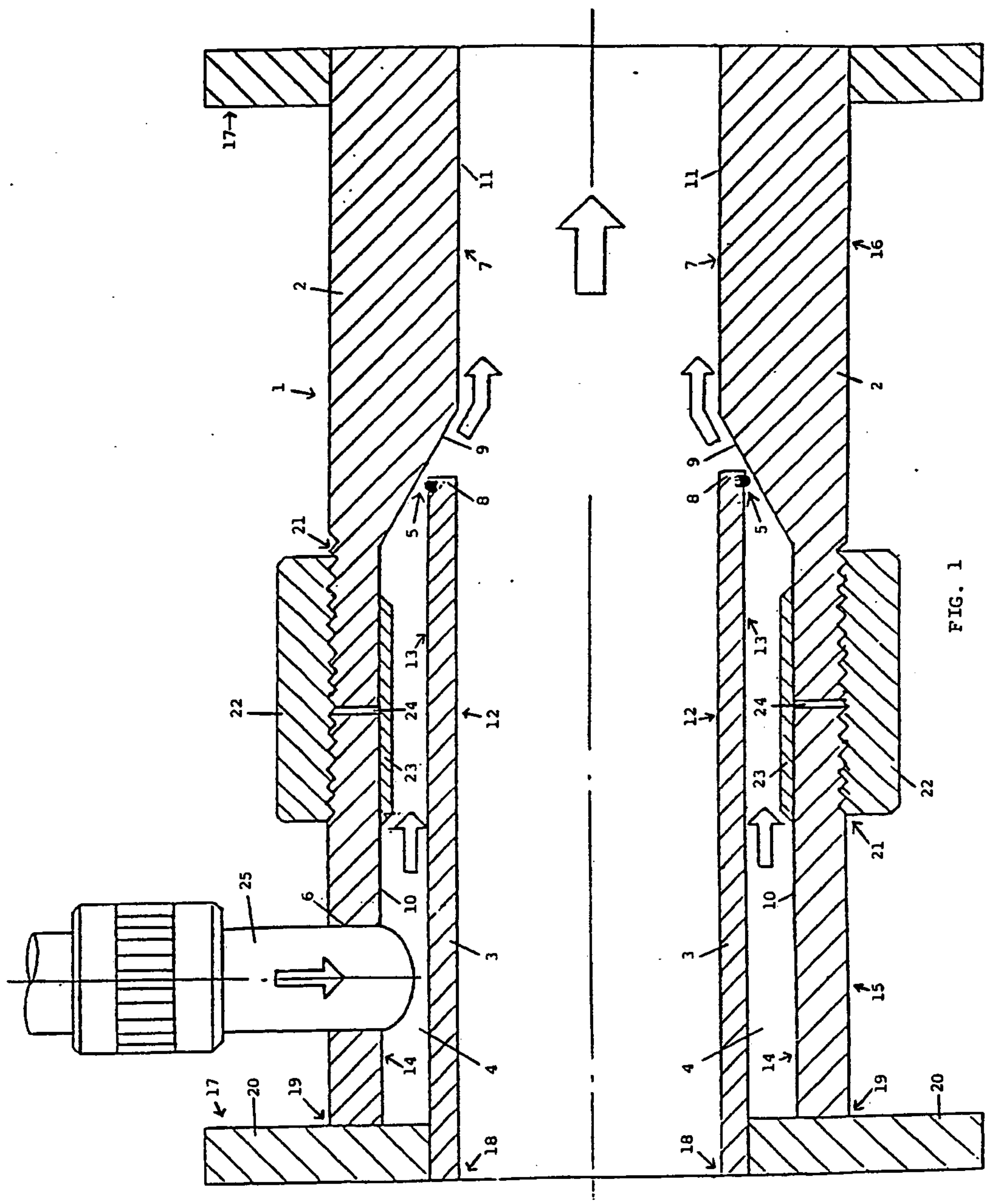


FIG. 1

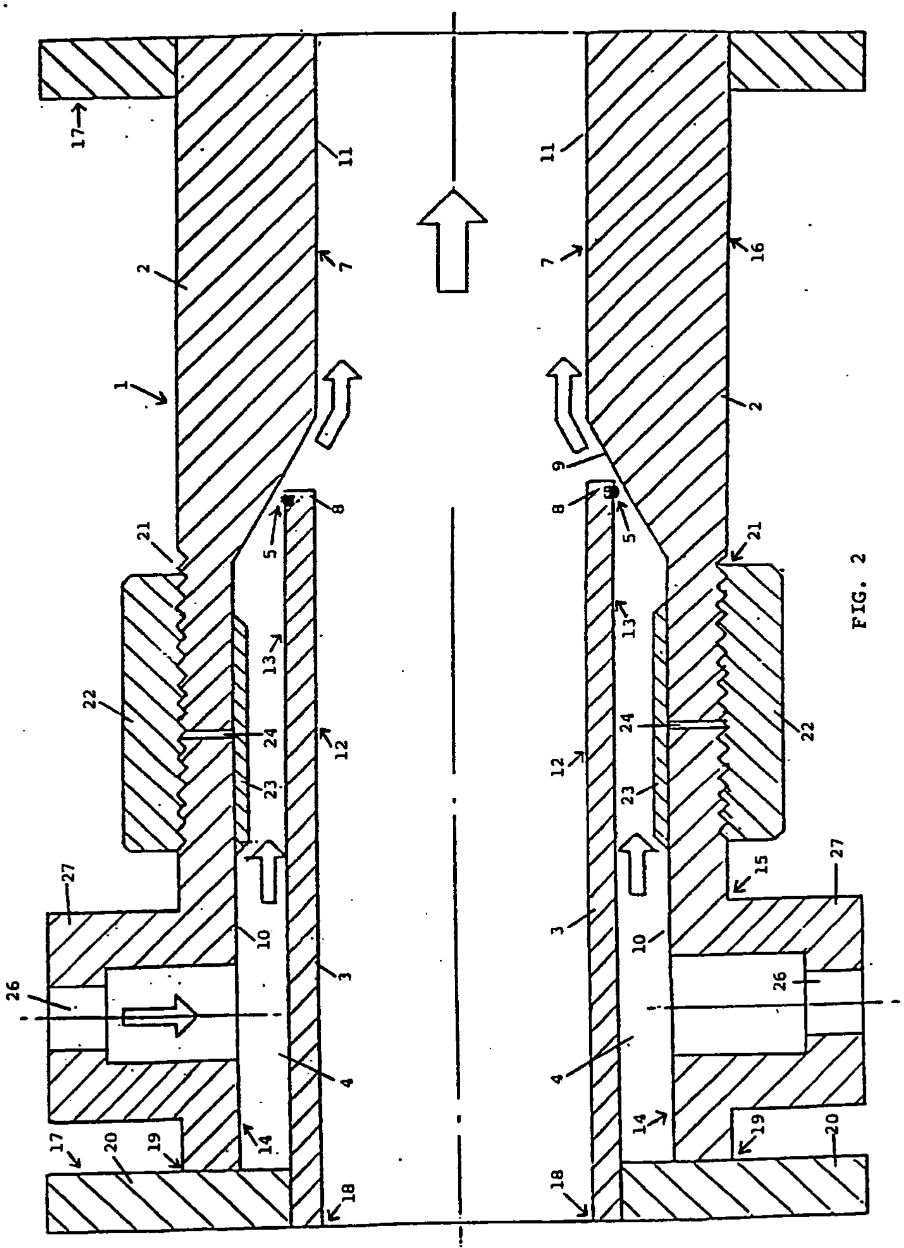


FIG. 2

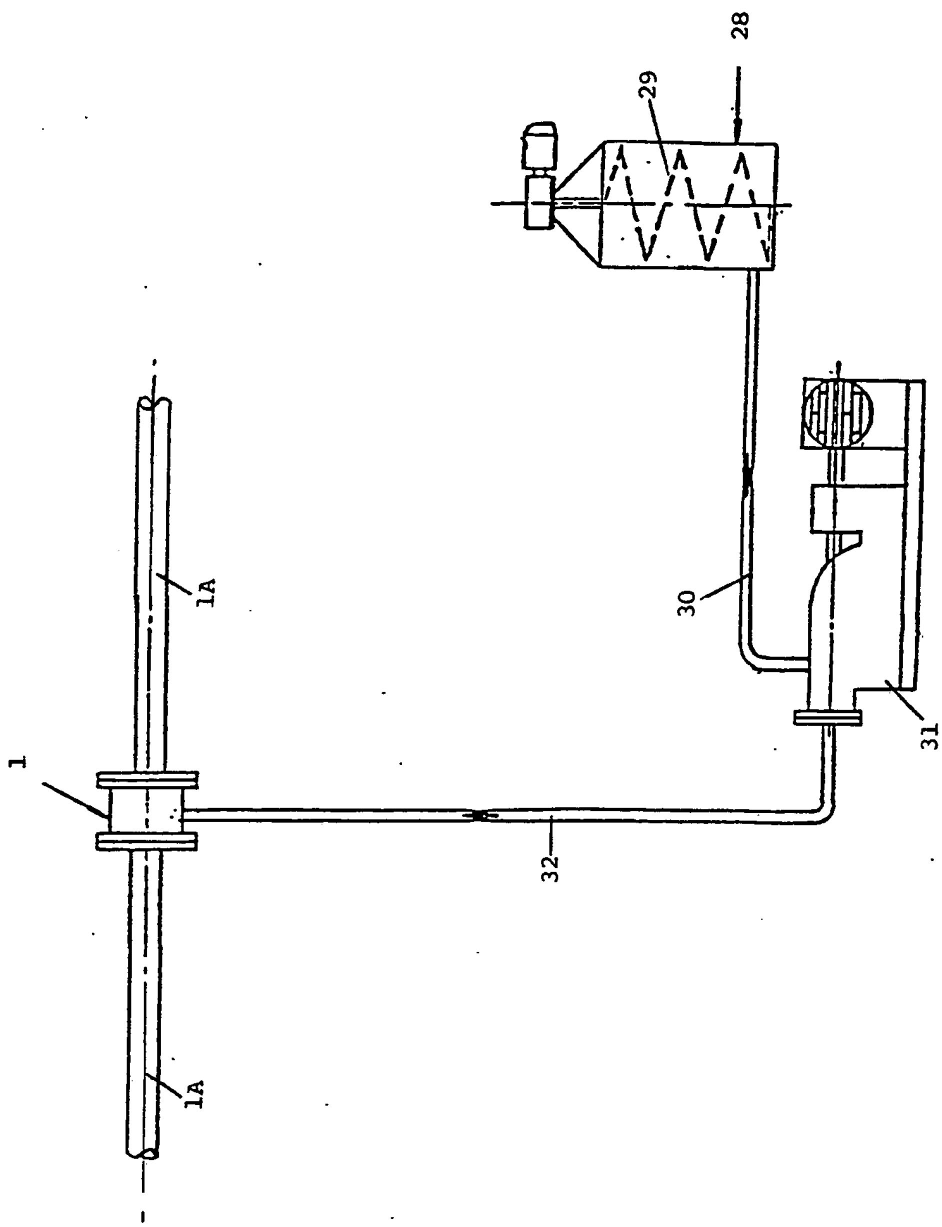


FIG. 3

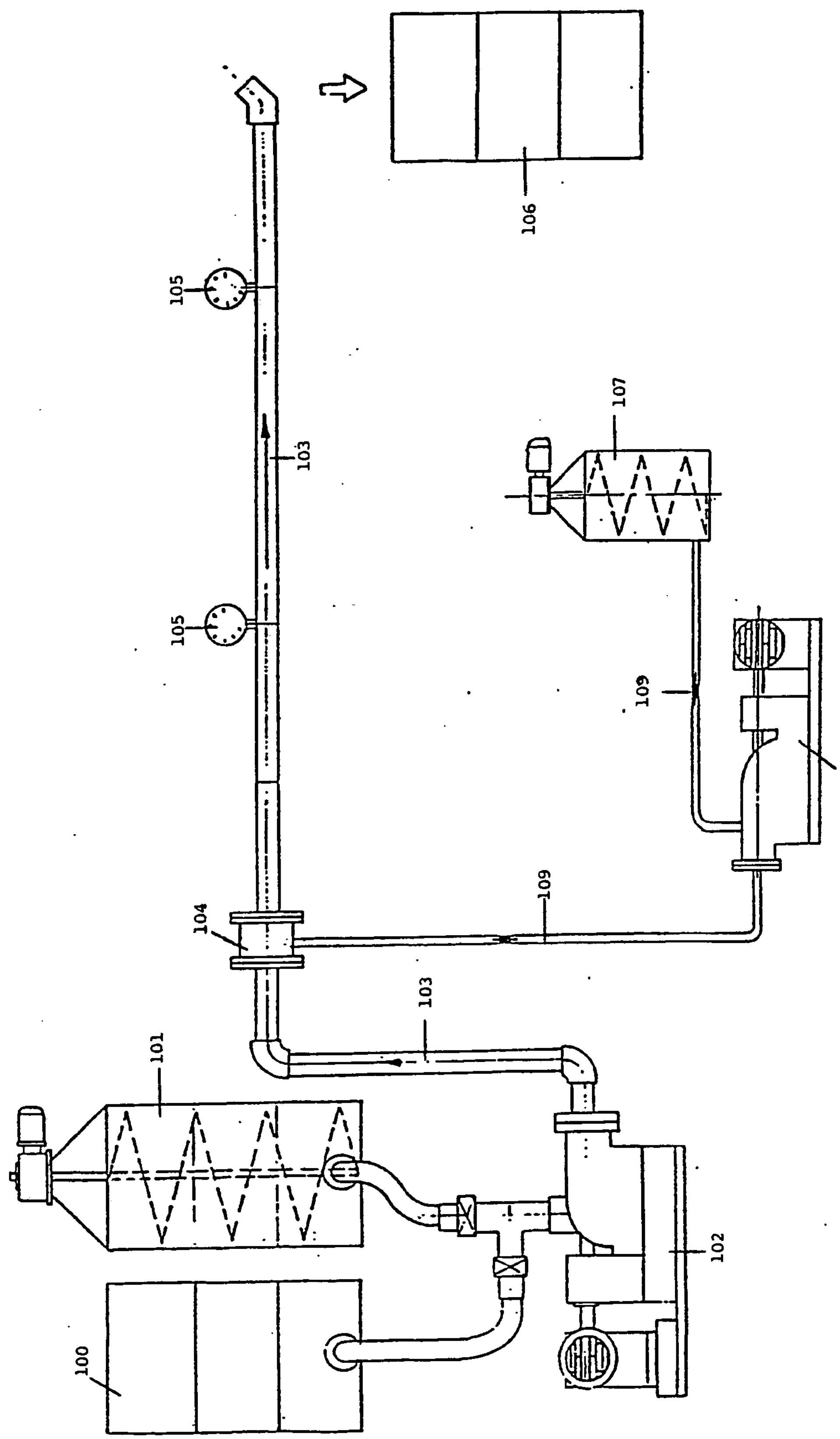


FIG. 4

INTERNATIONAL SEARCH REPORT

International Application No PCT/AU 87/00257

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl.^{4} F17D 1/16

II. FIELDS SEARCHED

Minimum Documentation Searched

Classification System	Classification Symbols
IPC	F17D 1/16

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched

AU : IPC as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
X	US,A, 3414004 (BANKSTON) 3 December 1968 (03.12.68)	(15-19)
X	US,A, 3502103 (VERSCHUUR) 24 March 1970 (24.03.70)	(15-19)
X	US,A, 3826279 (VERSCHUUR) 30 July 1974 (30.07.74)	(15-19)
X	US,A, 3892252 (POETTMANN) 1 July 1975 (01.07.75)	(1,8)
X	US,A, 3993097 (VERSCHUUR) 23 November 1976 (23.11.76)	(15-20)
X	US,A, 4047539 (KRUKA) 13 September 1977 (13.09.77)	(1,8)
X	US,A, 4273147 (OLNEY) 16 June 1981 (16.06.81)	(1,8)
X	US,A, 4259977 (BROCKINGTON) 7 April 1981 (07.04.81)	(1,8)

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
9 October 1987 (09.10.87)	(16.10.87) 16 OCTOBER 1987
International Searching Authority	**Signature of Authorized Officer**
Australian Patent Office	D.G. Fry D.G. FRY

Form PCT/ISA/210 (second sheet) (January 1985)

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON
INTERNATIONAL APPLICATION NO. PCT/AU 87/00257

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report	Patent Family Members		
US 3502103	DE 1756331 NL 6706568	FR 1561818	GB 1168608
US 3826279	BE 782362 FR 2135186 NL 7105973	CA 968009 GB 1389232	DE 2220794 IT 954787
US 3993097	BE 782361 FR 2134597 NL 7105971	CA 968010 GB 1389231 US 3822721	DE 2220793 IT 954788 US 3865136
US 4047539	CA 1008108 IT 1027127	DE 2460232	FR 2255549

END OF ANNEX